3.6.3 Carrier Generation-Recombination Models

Carrier generation-recombination is the process through which the semiconductor material attempts to return to equilibrium after being disturbed from it. If we consider a homogeneously doped semiconductor with carrier concentrations n and p to the equilibrium concentrations n_0 an p_0 then at equilibrium a steady state balance exists according to:

$$n_0 p_0 = n_i^2 \tag{3-306}$$

Semiconductors, however, are under continual excitation whereby n and p are disturbed from their equilibrium states: n_0 and p_0. For instance, light shining on the surface of a p-type semiconductor causes generation of electron-hole pairs, disturbing greatly the minority carrier concentration. A net recombination results which attempts to return the semiconductor to equilibrium. The processes responsible for generation-recombination are known to fall into six main categories:

- phonon transitions
- photon transitions
- Auger transitions
- surface recombination
- impact ionization
- tunneling

The following sections describes the models implemented into ATLAS that attempts the simulation of these six types of generation-recombination mechanisms.

Shockley-Read-Hall (SRH) Recombination

Phonon transitions occur in the presence of a trap (or defect) within the forbidden gap of the semiconductor. This is essentially a two step process, the theory of which was first derived by Shockley and Read [253] and then by Hall [96]. The Shockley-Read-Hall recombination is modeled as follows:

$$R_{SRH} = \frac{pn - n_{ie}^2}{\mathrm{TAUP0}\left[n + n_{ie} exp\left(\frac{\mathrm{ETRAP}}{kT_L}\right)\right] + \mathrm{TAUN0}\left[p + n_{ie} exp\left(\frac{-\mathrm{ETRAP}}{kT_L}\right)\right]} \tag{3-307}$$

where ETRAP is the difference between the trap energy level and the intrinsic Fermi level, T_L is the lattice temperature in degrees Kelvin and TAUN0 and TAUP0 are the electron and hole lifetimes. This model is activated by using the SRH parameter of the MODELS statement. The electron and hole lifetime parameters, TAUN0 and TAUP0, are user-definable in the MATERIAL statement. The default values for carrier lifetimes are shown in Table 3-65. Materials other than silicon will have different defaults. A full description of these parameters are given in Appendix B “Material Systems”.

Table 3-65 User-Specifiable Parameters for Equation 3-307			
Statement	**Parameter**	**Default**	**Units**
MATERIAL	ETRAP	0	eV
MATERIAL	TAUN0	1×10^{-7}	s
MATERIAL	TAUP0	1×10^{-7}	s

Note: This model only presumes one trap level which, by default, is ETRAP=0 and it corresponds to the most efficient recombination centre. If the TRAP statement is used to define specific trap physics then separate SRH statistics are implemented as described earlier in "Trap Implementation into Recombination Models" on page 113.

SRH Concentration-Dependent Lifetime Model

The constant carrier lifetimes that are used in the SRH recombination model above can be made a function of impurity concentration [234,157,78] using the following equation:

$$R_{SRH} = \frac{pn - n_{ie}^2}{\tau_p\left[n + n_{ie}exp\left(\frac{\mathrm{ETRAP}}{kT_L}\right)\right] + \tau_n\left[p + n_{ie}exp\left(\frac{-\mathrm{ETRAP}}{kT_L}\right)\right]} \tag{3-308}$$

where:

$$\tau_n = \frac{\mathrm{TAUN0}}{\mathrm{AN} + \mathrm{BN}\left(\frac{Ntotal}{\mathrm{NSRHN}}\right) + \mathrm{CN}\left(\frac{Ntotal}{\mathrm{NSRHN}}\right)^{\mathrm{EN}}} \tag{3-309}$$

$$\tau_p = \frac{\mathrm{TAUP0}}{\mathrm{AP} + \mathrm{BP}\left(\frac{Ntotal}{\mathrm{NSRHP}}\right) + \mathrm{CP}\left(\frac{Ntotal}{\mathrm{NSRHP}}\right)^{\mathrm{EP}}} \tag{3-310}$$

Here, N is the local (total) impurity concentration. The TAUN0, TAUP0, NSRHN, and NSRHP parameters can be defined on the MATERIAL statement (see Table 3-66 for their default values). This model is activated with the CONSRH parameter of the MODELS statement.